Effect of nursery feeding program on serum haptoglobin, growth performance, and carcass characteristics of pigs reared on commercial farms

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Abstract

A total of 774 pigs were enrolled in 13 cohorts across 7 commercial farms to examine the effect of nursery feeding program on serum haptoglobin, subsequent growth performance, and carcass characteristics of finishing pigs. Pigs were weaned [23.4 ± 0.2 days of age and 5.3 ± 1.5 kg body weight (BW)] and randomly assigned to either a complex (HC: highly digestible sources of proteins, including animal proteins; N = 346) or simple (LC: corn- and soybean meal-based; N = 340) diet for 37.7 ± 1.7 days over 3 phases (1 pen per diet per cohort; pen was the experimental unit; $n = 13$); sex was balanced between treatments. Thereafter, pigs received common grower-finisher diets. At a targeted BW of 118 kg, pigs (subset: $n = 275$ and 258 for HC and LC, respectively) were processed to evaluate carcass characteristics. Nursery feeding program did not influence BW, BW gain, or serum haptoglobin at any stage of production. Feed cost was reduced by $2.82 per pig during the nursery period for the LC-fed pigs ($P < 0.001$). Loin eye depth, back fat depth, carcass weight, percent lean yield, and carcass gross revenue at slaughter were not influenced by nursery feeding program. Feeding LC nursery diets on commercial farms is a feasible way to reduce feed cost without negatively impacting serum haptoglobin, growth performance during or after the nursery period, or carcass value.

Résumé

Un total de 774 porcs fut inclus dans 13 cohortes sur sept fermes commerciales afin d'examiner l'effet d'un programme d'alimentation en pouponnière sur l'haptoglobine sérique, les performances de croissance subséquentes, et les caractéristiques des carcasses des porcs en finition. Les porcs furent sevrés [23,4 ± 0,2 jours d'âge et 5,3 ± 1,5 kg de poids corporel (BW)] et assignés au hasard à une diète complexe (HC : source de protéines hautement digestibles, incluant des protéines animales; N = 346) ou une diète simple (LC : moulée à base de maïs et de soya; N = 340) pendant 37,7 ± 1,7 jours sur trois phases (1 parc par diète par cohorte; le parc était l'unité expérimentale; n *= 13); les sexes étaient équilibrés entre les traitements. Par la suite, les porcs recevaient une diète de croissance-finition commune. Au poids cible de 118 kg, les porcs (sous-groupe :* n *= 275 et 258 pour HC et LC, respectivement) étaient abattus pour évaluer les caractéristiques des carcasses. Le programme alimentaire en pouponnière n'a pas influencé le BW, le gain de BW, ou l'haptoglobine sérique à aucun stade de production. Le coût en aliment fut réduit de 2,82 $ par porc durant la période en pouponnière pour les porcs LC (*P *< 0,001). La profondeur de l'œil de la longe, l'épaisseur du gras dorsal, le poids de la carcasse, le pourcentage de rendement maigre, et le revenu brut par carcasse à l'abattage n'étaient pas influencés par le programme alimentaire en pouponnière. Nourrir avec une diète LC en pouponnière sur des fermes commerciales est un moyen réaliste de réduire les coûts en aliment sans affecter négativement l'haptoglobine sérique, les performances de croissance durant et après la période en pouponnière, ou la valeur des carcasses.*

(Traduit par Docteur Serge Messier)

Introduction

Early in the weaning phase, pigs are faced with several stressors simultaneously (such as adaptation to a solid diet, exposure to food allergens and pathogens, loss of maternal-derived antibodies, social stress, immature gut and immune system), which are often accompanied by a post-weaning growth lag and increased vulnerability to disease challenges (1). Highly digestible and expensive animal protein sources (including milk products, fishmeal, and blood by-products) are often included along with antibiotics in complex weaning diets to mitigate reductions in growth performance and prevent post-weaning infectious diseases (2,3). Some of these protein sources, however, are becoming increasingly difficult to source in Canada (e.g., whey protein, fishmeal), whereas others, such as blood meal and plasma, are excluded from pig diets due to biosafety concerns. Alternatively, soybean meal (SBM) is less expensive than animal proteins and may be fed as a major protein source to reduce the cost and the complexity of nursery diets. Such a feeding program has been shown to reduce pig growth during the nursery period compared to pigs fed nursery diets with highly digestible protein sources; however, the occurrence of compensatory growth during the late nursery and early grower phases resulted in similar body weight

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(BW) by the finisher phase (3,4). Furthermore, chemical body composition 8, 12, and 17 wk after weaning (4), carcass characteristics including carcass weight, back fat depth, loin eye depth, and percent lean yield at slaughter (4–6), and loin meat quality and distribution of carcass weight among retail cuts (4) were also not influenced by early-life feeding management.

The allergenic properties of the plant proteins found in SBM induce an inflammatory response in young pigs (7,8), which results in the partitioning of dietary nutrients away from net protein gain and toward activating and maintaining the immune response. Consequently, growth performance is negatively impacted (9). During inflammation, the concentrations of plasma acute phase proteins are adapted in response to pro-inflammatory cytokines (10). Thus, acute phase proteins, such as haptoglobin (HP), are used as indicators of inflammation or infection (11) and can be applied as a non-invasive means to evaluate animal health and well-being on commercial farms (12). We have shown previously that nursery diets containing SBM as the main protein source elevate serum HP concentrations in pigs 22 d after weaning, in a research setting (9).

Pigs on commercial farms are typically exposed to increased stocking densities and competition for resources, variable ventilation, and greater occurrence of clinical and sub-clinical disease challenges than those used for research. Therefore, assessing SBM as the main protein source in nursery diets on commercial farms is important before making recommendations to producers. We hypothesized that replacing animal proteins with SBM during the nursery period would reduce piglet growth and increase serum HP on commercial farms during the nursery period, but due to compensatory growth, similar BW would be achieved at the time of processing, and carcass characteristics would not be affected. The purpose of this study was to assess the effect of nursery feeding programs on growth performance, serum HP, and carcass characteristics of pigs reared on commercial farms.

Materials and methods

This study was approved by the University of Guelph Animal Care Committee and followed the Canadian Council of Animal Care guidelines (13).

Animals and general management

This study was conducted on 7 commercial farms in southern Ontario, Canada, located within a 2-hour radius of the University of Guelph over a 2-year period (May 2014 to June 2016). The farms were randomly selected and varied in size and type (e.g., farrow-to-finish *versus* off-site nursery and grower/finisher barns). One farm was antibiotic-free and the remaining 6 farms used in-feed antibiotics and/or zinc oxide during the nursery period. Six farms participated in 2 seasonal cohorts [i.e., summer (between May and August) and winter (between October and January)]; 1 farm participated in 1 cohort (total: 13 cohorts). In each of the 13 cohorts, a maximum of 60 piglets (Yorkshire × Landrace × terminal boar line) were randomly selected from 8 to 10 sows at 2.9 ± 0.1 days of age (DOA) and 1.87 ± 0.05 kg BW (N = 774; 372 males and 402 females). Piglets were individually identified with 2 ear tags; surgical castration of male pigs and administration of iron were conducted as per standard farm operating procedures.

Piglets were weaned at 23.4 ± 0.2 DOA and at 5.3 ± 1.5 kg BW. They were were moved to either an on- or off-site, environmentally controlled nursery room and were randomly assigned to 1 of 2 dietary treatments (approximately 30 pigs per pen; $n = 13$; pen was the experimental unit); sex was balanced between treatments wherever possible. After the nursery period, pigs were moved to an on- or off-site grower/finisher facility where the treatment groups were mixed together in 1 pen. Individual BW were collected at weaning and at the conclusion of each phase of growth (i.e., nursery, grower, and finisher). The average stocking density across the farms for the nursery period was 0.34 ± 0.03 m^2 per pig and for the grower and finisher periods was 0.77 ± 0.09 m^2 per pig. The number of pigs removed from the study (e.g., due to disease or euthanasia because of injury, cryptorchidism, poor growth, or low BW at weaning, and scrotal or umbilical ruptures, or loss of both ear tags) within in each phase (nursery, grower, finisher) was recorded and presented as a percent of total pigs remaining within each treatment.

Blood samples were collected from each pig at the time of measurement of BW, except for the initial visit. Blood was collected either *via* jugular venipuncture or orbital-sinus collection. Individual blood samples were centrifuged at 1500 × *g* for 20 min. Serum was separated and stored at −20°C until further analysis.

Diet, feed management, and nutrient analysis

At weaning, piglets were assigned to 1 of 2 dietary treatments for the nursery period which contained: i) highly digestible and multiple sources of proteins [including animal proteins; complex (HC)]; or ii) SBM as the major protein source [simple (LC)]. Both dietary treatments supplied similar formulated nutrient levels but varied in ingredient composition as outlined in Table I. The HC diet contained whey, fishmeal, and soy protein concentrate (HP300). The LC diet contained primarily corn and soybean meal, with whey (8%) and fishmeal (5%) only included in the first phase. The nursery diets were delivered in a 3-phase feeding program with phases I, II, and III fed for 8.7 ± 0.2, 14.9 ± 0.6, and 14.1 ± 0.9 d, respectively. Phase I was provided as a crumble and phases II and III were provided as short pellets. In-feed antibiotics and zinc oxide were used according to the standard operating procedure of individual farms. After the nursery period, all pigs were fed common grower and finisher diets according to industry standard that were not limiting in essential nutrients (14). The grower and finisher diets were delivered in multiple phases that varied according the farm-specific feeding program and were provided either as mash or pellets. Feed was always provided *ad libitum*, along with free choice access to fresh water.

Average daily feed offered (ADFO) per pig was calculated according to the quantity of feed added to each feeder during the nursery period, divided by the number of live pigs that had access to the feeder. Per pig feed cost for the nursery period was calculated by obtaining average monthly commodity prices (between May 2014 and June 2016) multiplied by estimated pig feed usage during the nursery period (ADFO). Feed intake or ADFO were not recorded during the grower and finisher periods.

The nursery diets were analyzed for crude protein (N × 6.25), Ca, and P contents (Agrifood Laboratories, Guelph, Ontario). Nitrogen

Table I. Ingredient and nutrient composition of experimental nursery diets.[a]

	Phase I		Phase II		Phase III	
Item	LC	HC	LC	HC	LC	HC
Ingredient composition (%, as-fed basis)						
Corn	47.40	13.70	48.92	32.30	46.84	47.04
Soybean meal (dehulled, 48% CP)	24.00	10.80	34.00	17.00	37.00	21.00
Wheat, soft red winter	10.00	—	10.00	—	10.00	—
Barley, 6 row	—	25.04	—	25.00	—	20.00
Whey, dried	8.00	20.00	—	8.00	—	—
Fat, animal vegetable blend	2.50	2.50	2.50	2.50	2.50	2.50
Fishmeal, mixed	5.00	5.00	—	3.00	—	—
Hamlet protein (HP300 product)	—	6.25	—	6.25	—	3.75
Alltech Nupro	—	3.75	—	2.50	—	1.25
Oat groats	—	10.00	—	—	—	—
L-Lys·HCl	0.16	0.30	0.25	0.25	0.05	0.35
DL-Met	0.11	0.19	0.17	0.16	0.08	0.17
L-Thr	0.02	0.08	0.09	0.08	—	0.13
L-Trp	—	0.02	—	0.02	—	0.02
Limestone	0.64	0.50	1.13	0.58	1.00	0.92
Salt	0.61	0.30	0.59	0.34	0.45	0.44
Monocalcium phosphate	0.69	0.07	1.48	0.52	1.27	1.29
Potassium diformate	—	0.20	—	0.20	—	0.10
Calcium proprionate	—	0.40	—	0.40	—	0.20
Saccharine	—	0.03	—	0.03	—	0.03
Vitamin and mineral mix[b]	0.87	0.87	0.87	0.87	0.81	0.81
Calculated composition, as-fed[c]						
DE (MJ/kg)	14.78	14.74	14.62	14.55	14.71	14.39
CP (%)	19.90	21.10	21.00	20.80	21.90	18.70
Total LYS (%)	1.23	1.43	1.34	1.35	1.27	1.25
SID LYS (%)	1.10	1.29	1.21	1.21	1.13	1.13
Ca (%)	0.94	0.94	0.83	0.83	0.74	0.74
P(%)	0.71	0.68	0.67	0.62	0.64	0.61
Analyzed composition, as-fed[d]						
CP (%)	20.58	21.14	21.06	20.18	21.00	19.46
Ca (%)	1.09	0.91	0.79	0.77	0.74	0.76
P (%)	0.75	0.69	0.73	0.63	0.72	0.69

[a] Experimental diets were based complexity of ingredients: Complex (HC) *versus* Simple (LC); phases I, II, and III fed for 8.7 ± 0.2, 14.9 ± 0.6, and 14.1 ± 0.9 d, respectively during the nursery period. All pigs received common grower and finisher diets thereafter that were not limiting in essential nutrients (14).

[b] Supplied per kilogram of diet: vitamin A, 12 000 IU as retinyl acetate; vitamin D3, 1200 IU as cholecalciferol; vitamin E, 48 IU as dl-α-tocopherol acetate; vitamin K, 3 mg as menadione; vitamin B12, 0.03 mg; pantothenic acid, 18 mg; riboflavin, 6 mg; choline, 600 mg; folic acid, 2.4 mg; niacin, 30 mg; thiamine, 18 mg; pyridoxine, 1.8 mg; biotin, 200 μg; Cu, 18 mg as $CuSO_4 \cdot 5H_2O$; Fe, 120 mg as $FeSO_4$; Mn, 24 mg as $MnSO_4$; Zn, 126 mg as ZnO; Se, 0.36 mg as $FeSeO_3$; and I, 0.6 mg as KI (DSM Nutritional Products Canada, Ayr, Ontario).

[c] Calculated based on the NRC (12) ingredient values.

[d] Nutrient analysis differed by $<$ 10% among farms (data not shown).

was determined by an automatic analyzer (LECO-FP 428; Leco Instruments, Mississauga, Ontario) (15). The P and Ca contents were determined as described by Heinonen and Lahti (16) and Themelis et al (17), respectively.

Determination of carcass characteristics

At a targeted minimum live BW of 118 kg, and approximately 30 d after collecting the final BW for the finisher period, a random subset of pigs from each of the cohorts (N = 533; 258 and 275 fed LC and HC diets during the nursery period, respectively) were sent to a provincial abattoir for processing and carcass evaluation according to the Canadian carcass grading system. Carcass evaluation included: hot carcass weight, loin eye depth, back fat depth, and calculated lean yield percent. Individual carcass gross revenue was calculated based on carcass evaluation and an Ontario payment grid used by Conestoga Farm Fresh (Breslau, Ontario), using a mid-range value of a $1.55/kg of dressed weight to minimize the influence of daily market fluctuations.

Serum haptoglobin analysis

Within each pen, a maximum of 15 pigs were randomly selected for serum HP analysis; serum HP was analyzed in these same pigs at the end of each phase (i.e., nursery, grower, finisher) using a pig-specific enzyme-linked immunosorbent assay (ELISA) kit (Zhongli District, Taoyuan city, Taiwan) according to the manufacturer's instructions.

Statistical analysis

Growth performance (BW, BW gain, and pig removal) and serum HP were analyzed using the GLIMMIX procedure of SAS (SAS Institute, Cary, North Carolina, USA) with the fixed effects of nursery diet (i.e., HC *versus* LC), stage of production, and the interaction between nursery diet and stage of production and using the repeated measures option; comparison of dietary treatments within stage of production were completed using the SLICE function. The BW at weaning and sex were considered as covariates but, when appropriate ($P > 0.10$), a reduced model was used. Farm (i.e., encompasses management, genetics, and environmental differences among farms), season (winter or summer), and pig within pen were included in the random statement. The nursery ADFO, nursery feed cost, and carcass characteristics after slaughter were analyzed in the same way but without the fixed effect of stage of production or the repeated measures option. For growth performance and serum HP, a log transformation was conducted to normalize the distribution of variation; means and standard errors were subsequently back-transformed. In all analyses, probability levels < 0.05 were considered significant, whereas $0.05 \leq P \leq 0.10$ was considered a trend, and $P > 0.10$ was considered not significant.

Results

General observations

The chemical analysis of the nursery diets were comparable to calculated values (Table I). Of the original 774 pigs enrolled in the study, 736 (370 and 366, for HC and LC, respectively) remained at weaning and 686 (346 and 340, HC and LC, respectively) remained at the end of the finisher phase. The interaction of stage of production and nursery feeding program did not influence any outcomes; therefore, only the main effects of nursery feeding program are presented.

Table II. Lifetime growth performance for pigs fed either HC or LC nursery diets.[a]

	Dietary treatment			*P*-value[b]
Item	LC	HC	SEM[c]	Diet
BW (kg)[d]				
Weaning	6.60	6.71	0.18	0.65
End of nursery	23.5	23.7	0.6	0.78
End of grower	59.4	59.5	1.4	0.91
End of finisher	101.2	102.4	2.5	0.72
Average daily gain (g)				
Nursery	419	422	10	0.85
Grower	848	848	19	0.99
Finisher	1007	1016	23	0.77
Pig removal (%)[e]	4.4	3.9	0.8	0.52
ADFO (g)[f]	684	673	62	0.77
Feed cost/pig ($)[g]	9.19	12.01	0.05	< 0.001
HP, g/L[h]				
Weaning	0.33	0.30	0.01	0.53
End of nursery	0.56	0.56	0.07	0.92
End of grower	0.54	0.55	0.07	0.85
End of finisher	0.58	0.63	0.06	0.65

[a] Experimental diets were based complexity of ingredients: Complex (HC) *versus* Simple (LC); phases I, II, and III fed for 8.7 ± 0.2, 14.9 ± 0.6, and 14.1 ± 0.9 d, respectively during the nursery period. All pigs received common grower and finisher diets thereafter that were not limiting in essential nutrients (14).
[b] *P*-values for the main effect of nursery feeding program.
[c] Maximum value of standard error of the means.
[d] Age of pigs at weaning = 23.4 ± 0.2 days of age (DOA; nursery feeding program initiation); end of nursery period = 61.1 ± 0.3 DOA (transition to common grower diet); end of grower period = 103.0 ± 0.3 DOA (transition to common finisher diet); end of finisher period = 145.3 ± 0.5 DOA.
[e] Average pig removal (e.g., due to mortality, identification loss, or severe morbidity) during the nursery, growing, and finishing phases.
[f] ADFO = average daily feed offered per pig during the nursery period.
[g] Calculated based on average cost of feed per pig during the nursery period, using ingredient monthly commodity prices between May 2014 and June 2016. Feed usage was based on calculated total feed budget per pig per phase: Phase I — 1.74 kg; Phase II — 8.88 kg; Phase III — 12.78 kg.
[h] Serum haptoglobin.

Growth performance and serum HP

Growth performance (BW and ADG) was not influenced by nursery feeding program during the nursery, growing, or finishing periods (Table II) but increased with stage of production ($P < 0.001$; data not shown). The pig removal rate (e.g., due to mortality, identification loss, or severe morbidity, etc.) for the nursery, grower, and

Table III. Carcass characteristics at ~118 kg live BW for pigs fed either HC or LC nursery diets.[a]

	Dietary treatment			*P*-value
Item	LC	HC	SEM[b]	Diet[c]
Hot carcass weight (kg)	104.2	104.6	1.5	0.88
Loin eye depth (mm)	67.7	68.3	0.8	0.59
Back fat (mm)	19.6	19.5	0.8	0.90
Lean yield (%)	60.7	60.7	0.3	0.92
Days to market (d)[d]	171	172	2	0.70
Carcass value ($)[e]	175.30	175.28	1.26	0.98

[a] Experimental diets were based complexity of ingredients: Complex (HC) *versus* Simple (LC); phases I, II, and III fed for 8.7 ± 0.2, 14.9 ± 0.6 and 14.1 ± 0.9 d, respectively during the nursery period. All pigs received common grower and finisher diets thereafter that were not limiting in essential nutrients (14).
[b] Maximum value of standard error of the means.
[c] *P*-values for the main effect of nursery feeding program.
[d] Number of days between birth and day of processing.
[e] The average gross revenue of each individual carcass was based on a mid-value price of $1.55/kg of dressed weight and a payment grid used commonly in Ontario.

finisher periods was not influenced by the nursery diet (Table II) but decreased with stage of production ($P < 0.001$; data not shown). The ADFO for the nursery period was not influenced by the nursery feeding program (Table II) but feed cost for the nursery period was $2.82 less per pig for those fed the LC nursery diet *versus* those fed the HC diet ($P < 0.001$; Table II). Serum HP was not influenced by the nursery feeding program at the end of the nursery, grower, or finisher periods (Table II) but increased over time ($P < 0.001$; data not shown).

Carcass characteristics

Carcass characteristics were evaluated for 275 pigs (134 gilts and 141 barrows) that were fed the HC diet and 258 pigs (117 gilts and 141 barrows) that were fed the LC diet during the nursery period. Hot carcass weight, loin eye depth, back fat depth, lean yield, dressing percent, and carcass value were not influenced by nursery feeding program (Table III).

Discussion

The main purpose of the current study was to determine if nursery diets with reduced inclusion levels of highly digestible, and expensive protein sources influenced growth performance, serum HP, and carcass characteristics at slaughter, when implemented on commercial farms. Nursery diets with high inclusion of SBM have been shown to induce an inflammatory response in young pigs due to allergenic properties of plant proteins (7,8), which in combination with increased stocking density and competition for resources, variable ventilation, and increased occurrence of clinical and sub-clinical disease challenges on commercial farms could permanently impact pig growth, health, and value. We found that feeding a simple, corn- and SBM-based nursery diet is feasible on commercial farms, with no negative long-term effects on growth performance, serum HP, or carcass characteristics and carcass value. Using this approach and given the cost of ingredients at the time of this study, it was possible to reduce nursery feed cost by $2.82 per pig. If implemented on commercial farms, this strategy could reduce the reliance on expensive protein sources like whey and fishmeal (i.e., that are becoming increasingly difficult to source in Canada), or protein sources that are excluded from pig diets due to biosafety (e.g., blood meal and blood plasma) or environmental sustainability (e.g., fishmeal) concerns.

In previous studies, we showed that growth was reduced during the nursery period for pigs fed diets based on corn and SBM *versus* those fed diets that included highly digestible, animal protein sources [whey, herring meal, blood plasma, and meal (4,9)]. As the growth-lag is most apparent within the first 7 d after weaning (1,18) and up to 21 d when feeding nursery diets based on plant proteins (3,4,19), it is possible that the interval between BW measurements during the nursery period in the current study (37.7 ± 1.7 d) may have precluded the detection of reduced growth. Additionally, most farms enrolled in the current study used in-feed antibiotics and/or zinc oxide during the nursery period, which may have mitigated negative effects of a LC nursery feeding program on BW gain. In a study by Skinner et al (4), inclusion of antibiotics into nursery diets based on plant proteins improved pig growth, so the ADG was not different from those fed diets based on animal-sourced proteins with no antibiotics. Moreover, previous studies conducted on nursery feeding programs used Yorkshire × Landrace or purebred Yorkshire pigs, rather than hybrid terminal crosses used in the present study. The genetic robustness that promotes efficient and rapid growth of terminal cross pigs may have positively influenced the pigs' ability to maintain high rates of growth, despite reduced nursery diet complexity (20).

Immune system stimulation results in increased production of pro-inflammatory cytokines and acute phase proteins. This is accompanied by reduced growth performance both due to anorexia as well as the partitioning of nutrients away from growth to support the immune system (21,22). In particular, the acute phase protein, HP found in blood, can be used as an indicator of non-specific infection or inflammation and as a biomarker for reduced pig growth (23–25). In the current study, there were no differences in serum HP concentrations due to nursery feeding program. This indicates that the SBM in the LC diets did not stimulate the immune system or increase susceptibility to disease and induce the repartitioning of dietary nutrients away from BW gain. As with the growth performance data, sampling may have occurred too infrequently to detect differences in serum HP. Indeed, in a previous study, we demonstrated an increase in serum HP for pigs fed LC diets 22 d after weaning *versus* those fed diets with higher quality, animal-based proteins, but differences were no longer detectable by 28 d post-weaning (9). Furthermore, serum HP concentrations were below the range of those reported by Piñeiro et al (26) but followed the same trend overtime. The former is attributed to the statistical analyses used to account for the variation within the model.

Finally, the nursery feeding program did not influence carcass characteristics or gross revenue, which agrees with previous studies that demonstrated no effect of early life nutritional interventions on carcass characteristics (4,6,19). In conclusion, the current study suggests that feeding corn- and SBM-based nursery diets with reduced inclusion levels of animal proteins on commercial swine farms is a feasible way to reduce nursery feeding cost, without influencing subsequent health, growth performance, or carcass value.

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